FORMATION OF HIGH-LATITUDE PEDESTAL CRATERS. K. E. Wrobel[1], P. H. Schultz[1], and D. A. Crawford[2], [1]Department of Geological Sciences, Brown University, Box 1846, Providence, RI 02912 (Kelly_Wrobel@brown.edu), [2]Sandia National Laboratories, P. O. Box 5800, MS 0836, Albuquerque, NM 87185.

Introduction: Prior to and just after an impact on Mars, a small fraction of the total impact energy is directly coupled to the ambient atmosphere. A resulting hemi-spherical shock wave propagates outward leaving a signature that is dependent on initial atmospheric and surface conditions. Here we propose that the distinctive pedestal craters common at high latitudes on Mars are a direct consequence of extreme winds and elevated temperatures generated by this atmospheric blast.

Background: Previous studies have generally centered on the later time indirect coupling of impact energy to an atmosphere from high-speed ejecta, expanding impact-induced vapor, frictional drag, etc. [e.g., 1-4]. The atmospheric response to early time direct energy transfer and its possible expression on the surface also have been examined using analytical expressions [e.g., 1, 5]. This early time energy transfer can be computationally modeled as a point-source instantaneous release of a large amount of energy into a small volume of gas during a short time interval. Such a model was constructed in this study using the CTH shock physics analysis package [6] with adaptive mesh refinement [7] to maintain high resolution along the resulting blast front.

Energies corresponding to .1% and 1% of the total impact energy required to create a 10 km diameter crater (6 km "apparent" pre-collapse crater) on Mars was coupled to a CO_2 atmosphere (specific heat ratio of 1.3) with an ambient density of 1.55e-5 g/cc and an ambient temperature of ~240 K at y=0.

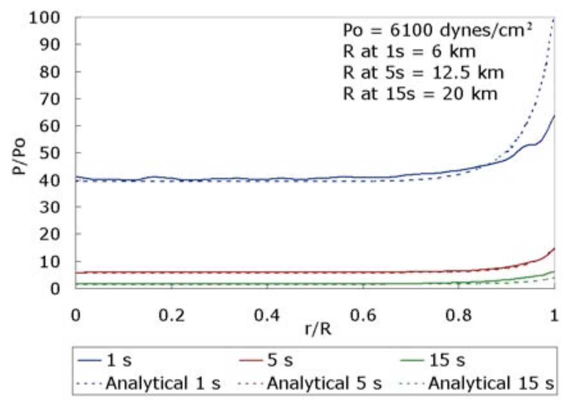

Figure 1: Comparison of analytical calculations with computational modeling results for a point source explosion in the Martian atmosphere. R denotes the position of the shock front and P_o is the ambient atmospheric pressure. Energy is .1% of the initial kinetic energy required to produce a 10 km diameter crater (6 km apparent diameter).

The results were compared to calculations obtained analytically using previous work on the formation of a blast wave by an intense explosion [8] and show a very good correlation (see Figure 1).

Results: Earlier studies [1] found that if .1% (1%) of the initial energy of an impact is directly coupled to the Martian atmosphere, blast zone effects may be observed out to 4 crater diameters (10 crater diameters). This also was observed in both the analytical and computational results obtained in the present study: the pressure in the shock front equilibrated to ambient pressure when it arrived at ~4.2 (~9.8) crater diameters from the explosion.

Figures 2 and 3 show results from the computational model for the two different runs (.1% and 1% energy coupling) at the locations marking the return of the front to ambient pressure. These plots reveal that the surface surrounding a 10 km diameter crater on Mars will be subjected to both a fast blast wave (followed by recovery winds – negative velocities) and a large temperature pulse. Because such a crater requires about 20 seconds to form, these intense winds and high temperatures will not only "pre-condition" the surface prior to ejecta emplacement, but will also extend to much greater distances.

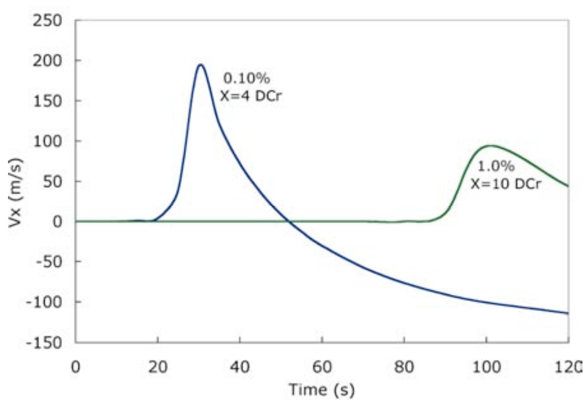

Figure 2: Horizontal velocity (cm/s) as a function of time (s) for y=0 (surface) from computational models of point source explosions releasing .1% and 1% of the total energy necessary to create a 10 km diameter crater (6 km apparent diameter). Results are displayed for x=4 apparent crater diameters (.1%) and x=10 apparent crater diameters (1%) for these positions mark the distances at which the shock front pressure equilibrates to ambient pressure [1].

Residual temperatures behind the blast wave are much higher than ambient conditions, particularly close to the crater (1000 K at 2 crater diameters). At greater distances (e.g., 4 crater diameters), atmospheric temperatures will radiate into the upper surface and produce a thermal wave that can extend down to ~25 cm in only 75 seconds for an ice-rich substrate (see geothermal profile equation in [9]). Thus, if given enough time, sufficient temperatures to melt ice can be achieved below the surface due to lingering high atmospheric temperatures.

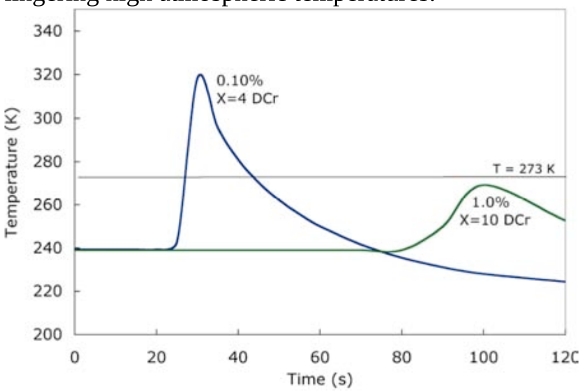

Figure 3: Temperature (K) versus time (s) for y=0 (surface) from computational models of point source explosions releasing .1% and 1% of the total energy required to produce a 10 km diameter crater (6 km apparent diameter). Positions used (DCr stands for apparent crater diameter) correspond to the distances at which the shock fronts equilibrate to ambient pressure.

Implications: Prior to ejecta emplacement, powerful winds (> 100 m/s) will sweep over the region surrounding an impact, thereby stripping the surface of loose soil and dust. The surface will then be immersed in an atmosphere with temperatures exceeding 273 K over times approaching 1 minute (even for the case of .1% coupling). This one-two "punch" should have particular significance for regions covered by an ice-rich mantle, e.g., high latitudes. Such a process may be expressed by scoured zones (characterized by radial striations and muting of surface detail) that surround fresh high-latitude craters and extend well beyond the continuous ejecta (Figure 4a). Heating of the subsurface also can result in melting and migration of water. This, in turn, may lead to induration of soil grains through time, creating an armored surface.

Volatile-rich surface layers at high latitudes are highly susceptible to erosion over short times as a response to orbital forcing [11]. The calculated atmospheric blast and subsurface thermal wave discussed here would form a crater-centered erosion-resistant surface layer, such as those observed for pedestal craters on Mars (Figure 4b). Pedestal craters were first recognized with Mariner 9 data [10]. These distinctive crater relicts occur at high latitudes and in equatorial mantling deposits [11]. Although previously attributed to the presence of volatiles [e.g., 5, 11-14], the details of pedestal crater formation have been difficult to address without numerical models and clear evidence that volatiles are near the surface [15].

Martian pedestals can extend up to ~10 crater diameters depending on crater size, age, and location [5, 11]. Based on our preliminary study, energy coupling of at least 1% into an atmospheric blast would be necessary to create an erosion-resistant surface lag out to a distance of 10 crater diameters.

More detailed modeling (benchmarked by laboratory experiments) is needed to test the relative roles of the atmospheric blast and temperature pulse for different volatile-rich lithologies. This, in turn, will help assess locations of past volatiles across Mars.

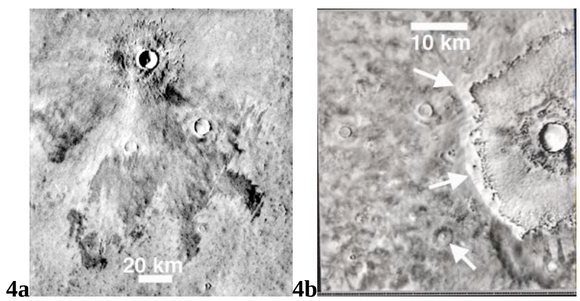

Figure 4: (4a): Image of a ~12 km diameter Martian pre-pedestal crater. Scouring of the surface extends to ~8 crater diameters. (4b): Image of a ~6 km diameter Martian pedestal crater. Pedestal extends out to ~4 crater diameters. The bottom arrow points out an example of a much smaller pedestal crater.

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